

## ADVANCED PHOTOVOLTAIC SOLAR ARRAY DESIGN ASSESSMENT

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The Advanced Photovoltaic Solar Array (APSA) program seeks to bring to flight readiness a solar array that effectively doubles the specific power of the SAFE/SEP design that was successfully demonstrated during the Shuttle 41-D mission. APSA is a critical intermediate milestone in the NASA-OAST effort that has, as its goal, to demonstrate solar array technologies capable of 300 W/kg and 300 W/m<sup>2</sup> at beginning of life. The APSA program, at its completion, should yield a flight ready, high performance solar array that can efficiently accommodate the types of solar cells required to provide either a 300 W/kg or 300 W/m<sup>2</sup> array.

The genesis for such ambitious goals was the demonstration that ultrathin (50  $\mu$ m) silicon solar cells with very high (~15 percent) conversion efficiency could be fabricated (ref. 1). During the nearly 10 years that it took to bring the prototype cell to a state of flight readiness, parallel activities addressing ultrathin cell laydown and interconnection, suitable flexible blanket substrates and covers (ref. 2), plus compatible, efficient array structures (ref. 3) were conducted. The success of these programs led to the decision to commit to the APSA program.

## PROGRAM DEFINITION

APSA was conceived as a multiyear three-phase effort. The initial phase was to address the development of a realistic design that would incorporate existing elements of advanced array technology and was capable of accommodating anticipated advancements. This would be followed by a fabrication phase in which, as a goal, protoflight hardware would be demonstrated on a scale that would assure user confidence in manufacturing the technology. This would then lead to a ground test phase in which the protoflight hardware would be subjected to the types of generic tests required for space-qualified arrays.

Establishing meaningful, challenging goals for the APSA Program was considered essential for success. Generic targets such as W/kg and W/m<sup>2</sup> would not be sufficient to assure that the technology would be considered by the users for future mission applications. Orbit, mission duration and spacecraft function were other factors that had to be addressed. These, in turn, would influence array stiffness and circuit architecture at one level and cell and coverglass selection at another.

In order to involve the community in the process of goal definition, a survey was taken where the respondents were asked to not only provide array design targets but justify them in terms of perceived missions. The entire space community was invited to participate, even though the array technology to be developed was for NASA specific mission objectives. This was done in the hope that the APSA baseline array technology would have a wide appeal to mission users, thus enhancing its prospects for flight use.

## APSA DESIGN REQUIREMENTS

Performance requirements were then established by JPL for the APSA design based partially upon the results of the survey. In addition, an analysis was performed to establish the array performance that would be anticipated from the component characteristics developed as part of the OAST advanced array technology program. A third aspect of the requirements was to limit the scope of the two contractors' efforts so as to remain within the overall available budget and still determine a "highly probable" advanced array design with acceptable detail.

These considerations led to the following design requirements:

8 to 12 kW BOL  
130 W/kg BOL  
105 W/kg EOL  
110 W/m<sup>2</sup> EOL

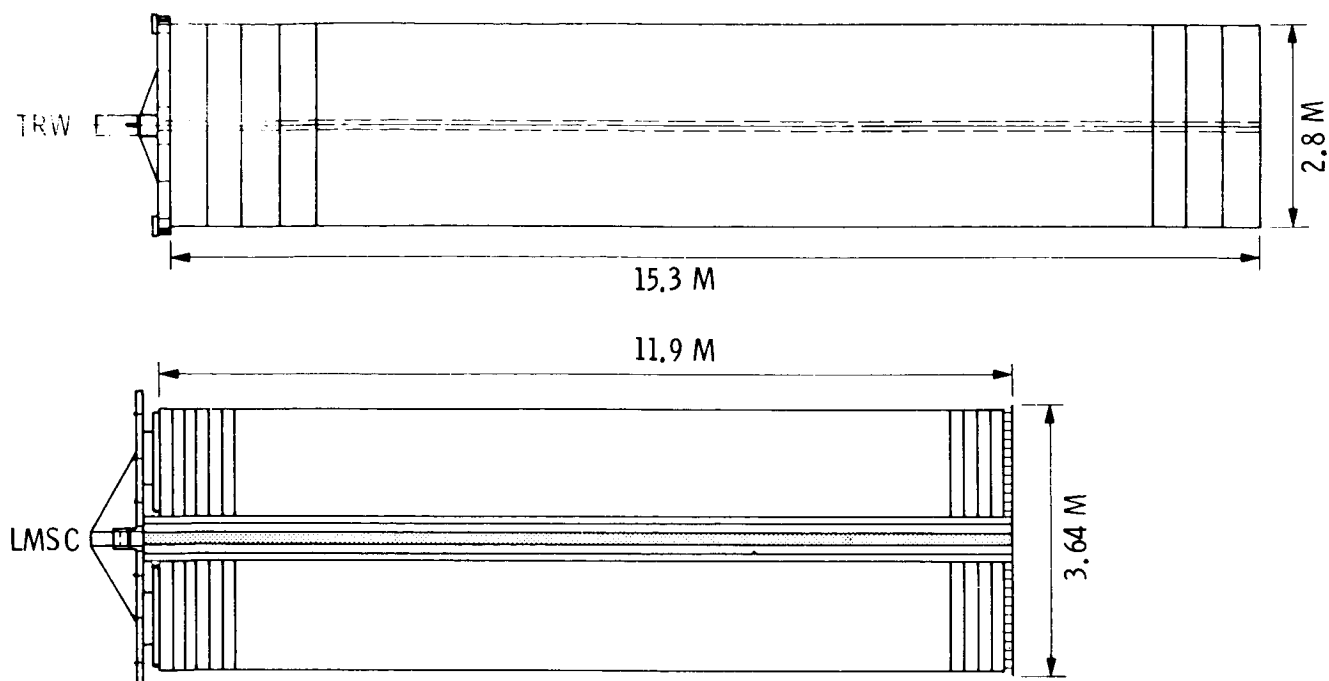
with EOL defined to be 10 years in the baseline geosynchronous orbit. Although the restriction to geosynchronous orbit eliminates many other important future missions from detailed analysis, it did contain two important features. First, the most frequently mentioned use of an advanced high performance array with power level on the order of 10 kW is for geosynchronous communications satellites. Second, this type of orbital environment is more closely related to the environment expected for interplanetary array use, an obviously important consideration for NASA-OAST developed technology. Naturally, other orbital environments can be imposed on the developed designs by interested parties to determine suitable "scaling factors." Other requirements included the need for shuttle launch environment compatibility and the demonstration of technology maturity so as to allow for a subsequent fabrication of protoflight hardware based on the advanced array technology.

Once the contracted efforts began, some additional requirements were developed to assure that the merits of the competing designs could be meaningfully compared. These were as follows:

- (1) Deployed wing frequency to be evaluated over the range 0.01 Hz to 0.10 Hz (cantilevered).
- (2) On-orbit wing loads to be evaluated over the range  $10^{-3}$  to  $10^{-2}$  g ultimate.
- (3) Partial extension, partial and full retraction, and full restowage were not required.
- (4) Array voltage levels shall not exceed 200 volts BOL open circuit at normal operating temperature.
- (5) Array shadowing is not to be assumed.
- (6) Trapped radiation and solar flare environments are as specified by JPL.

## CANDIDATE DESIGNS AND SELECTION

Figure 1 summarizes the two final designs. Not unexpectedly, there was some degree of similarity in that both decided to propose a basic array structure featuring a coilable longeron mast deployed from a canister. Each blanket design employed 65  $\mu$ m silicon solar cells, thin ceria-doped microsheet covers and a Kapton-based substrate.



	LMSC	TRW
CELL	7.1 X 7.1 CM X 65 $\mu$ M WRAPTHROUGH CONTACT $\eta$ = 13.3%	2 X 4 CM X 65 $\mu$ M $\eta$ = 13.5%
COVER	16 X 35.7 CM X 75 $\mu$ M Ce MICROSHEET	2 X 4 CM X 50 $\mu$ M Ce MICROSHEET
SUBSTRATE	74 $\mu$ M THICK PRINTED CIRCUIT, Cu/KAPTON	50 $\mu$ M THICK CARBON LOADED KAPTON
DEPLOYMENT MAST	CONTINUOUS LONGERON 16.3 CM DIAM. 3.8 MM D. LONGERON	CONTINUOUS LONGERON 20.8 CM DIAM. 3.8 MM D. LONGERON
CANISTER	GRAPHITE/EPOXY	ALUMINUM
CONFIGURATION	ACCORDIAN FOLD DUAL BLANKET IN PLANE MAST	ACCORDIAN FOLD SINGLE BLANKET REAR SIDE MAST
SPECIFIC PERFOR- MANCE, BOL WITH 5% CONTINGENCY	138 W/KG	145 W/KG

Figure 1. APSA Design Candidates

There were also some interesting differences in that one proposed a single blanket wing as opposed to the other's dual blanket approach. Although there was only a one percent difference in total wing area, the selected wing aspect ratios were quite dissimilar. There was also a wide divergence in opinion on cell size and configuration, as shown in Figure 1. Perhaps the greatest surprise was the fact that there was not agreement on the method of cell interconnecting; one opting for welded, the other solder.

The selection process focused on technical maturity (risk) since protoflight hardware was required in the second phase of the APSA program. Cost constraints were also a significant factor in the selection process, since it was considered essential that the protoflight hardware include all the components that constitute an operating array. This was mandated by the architecture and total funding of the APSA program which must culminate in ground-based testing of the total array design.

Even though only one design could be chosen, it should be noted that the APSA design phase has shown that at least two solar array design options exist for meeting this critical NASA-OAST milestone for advanced solar array technology. Hopefully, other agencies or flight program offices that require this type of solar array improvement will give attention and support to the alternate APSA design.

#### APPROACHES TO ENHANCING APSA PERFORMANCE

The APSA design represents a significant improvement in array specific power performance, but substantial work remains in order to achieve the ambitious 300 W/kg and 300 W/m<sup>2</sup> goals set by NASA-OAST. Analysis of the APSA components shows that solar cell performance improvements offer the greatest leverage for future progress. It should be noted at this point that the NASA-OAST goal of 300 W/kg was established for an array capable of delivering 25 kW at beginning of life. Thus, in the subsequent discussion of APSA, all quoted specific power forecasts should be escalated by approximately 15 percent to account for the advantages (deployment and stowage mass contributions) associated with scaling this design to the appropriate NASA-OAST power level goal.

Figure 2 depicts the APSA performance that would be achieved by the substitution of higher efficiency and lower mass (equivalent to 10  $\mu$ m of silicon) solar cells with no other array changes made. Based on previous results in developing high efficiency 62  $\mu$ m silicon cells (ref. 1) and recent work demonstrating efficiencies approaching 18 percent for 300  $\mu$ m silicon cells (ref. 4), it would appear reasonable to forecast that 16 percent 62  $\mu$ m silicon cells could be mass produced in the near term. This would raise the APSA specific power to at least 175 W/kg, translating to approximately two-thirds (200 W/kg) of the NASA-OAST goal.

Thin film solar cells appear to hold the most promise for going beyond the 200 W/kg performance level. To give some perspective to this statement, the current status of various thin film solar cell candidates is included in Figure 2. It should be mentioned that these efficiency values represent the best that have been achieved to date under laboratory conditions. It would not be unrealistic to anticipate that a single crystal, thin film solar cell could achieve a realistic (manufacturable) conversion efficiency of 18 percent provided that sufficient resources were devoted to its development. This would likely satisfy the NASA-OAST goal of 300 W/kg.

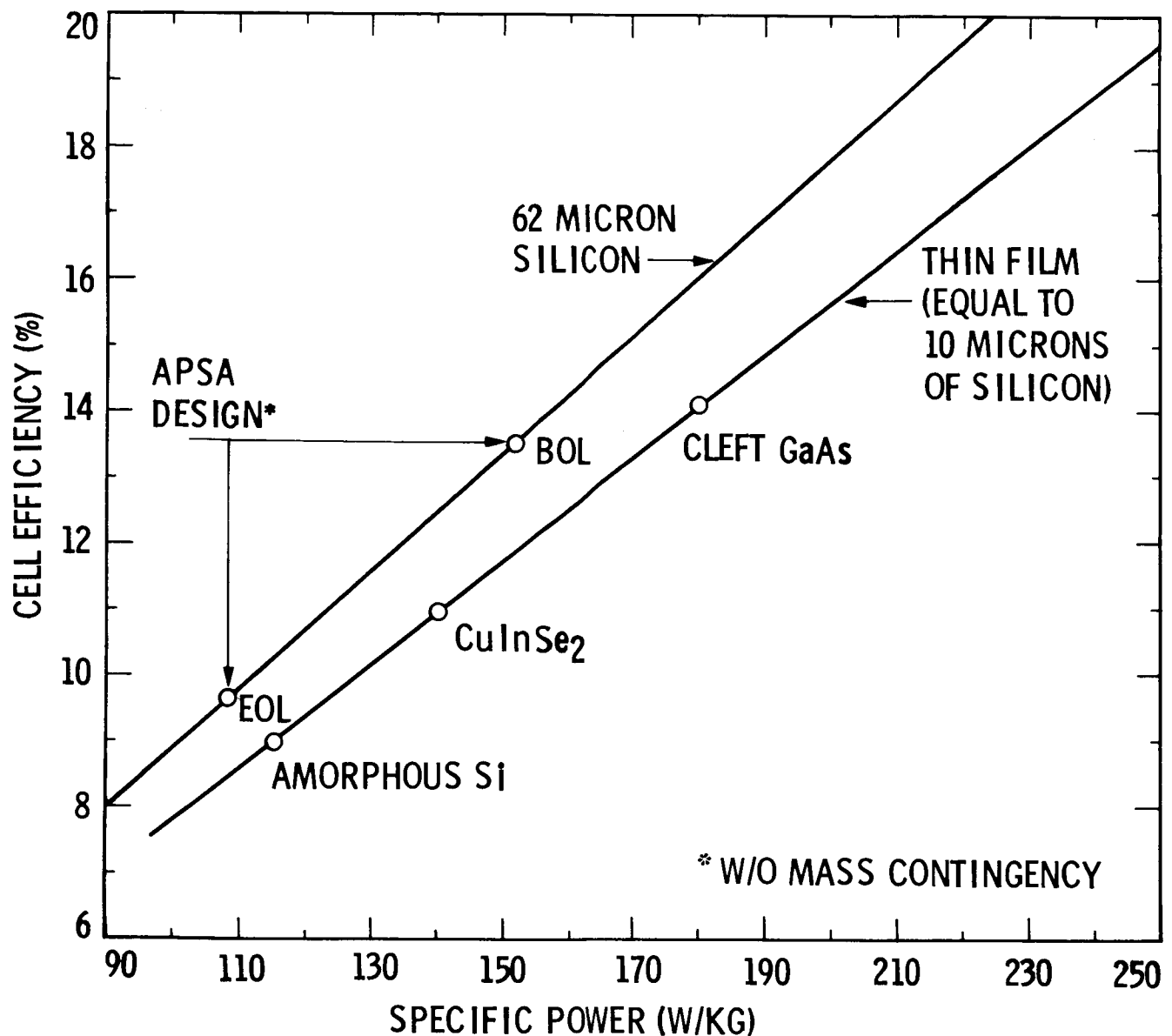


Figure 2. Impact of Advanced (Thin) Cells on APASA Design

Although the OAST goals are expressed in terms of beginning-of-life (BOL), it is necessary, when actually evaluating a mission, to design the array for maximum specific power at end-of-life (EOL). From this perspective, many of the thin film solar cells look potentially attractive for high performance solar arrays. Based on admittedly limited radiation test data, materials such as amorphous silicon and CuInSe<sub>2</sub> show considerable promise, especially for missions that would experience very high (approaching  $1 \times 10^{16}$  e/cm<sup>2</sup>) radiation environments. For example, a thin film solar cell that yields 9 percent conversion efficiency after an equivalent 1 MeV fluence of  $1 \times 10^{15}$  e/cm<sup>2</sup> would result in greater than 200 W/kg specific power at EOL for a solar array operating for 10 years in a geosynchronous orbit.

In summary, it is not unreasonable to anticipate the development of solar array designs capable of 300 W/kg at BOL for operational power levels  $\geq 25 \text{ kW}_e$ . It is also quite reasonable to expect that high performance solar arrays capable of providing at least 200 W/kg at EOL for most orbits now being considered by mission planners will be realized in the next decade.

#### REFERENCES

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